

THE SOIL may be likened to a vast chemical laboratory in which complicated changes are constantly going on. It is difficult to describe what occurs in this great laboratory briefly and in nontechnical language. In the first part of this article the general reader becomes acquainted with some of the elementary facts about soil colloids, base exchange, soil acidity, and the soil solution. The last part of the article deals with these subjects in more detail for readers who have some acquaintance with elementary chemistry.

General Chemistry of the Soil

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SOME ELEMENTS OF SOIL CHEMISTRY

THE chemistry of the soil involves many and very different chemical compounds. The most important group is composed of the compounds of the element silicon, which make up more than 75 percent of the various soil layers. The silicon compounds of soil are derived from the decomposition of every kind of silicate rock on the face of the earth. The products of these rocks have been modified in part by the action of plants and animals of all kinds growing on the soils and contributing their remains to the already complex soil material. The remains of living organisms usually contribute from 1 to 10 percent of the weight of the upper few inches of surface soil. The silicon compounds and the carbon compounds, associated with life processes, are the most numerous and the most complex of the compounds found in nature.

In each class certain relatively simple compounds may be separated and identified. Crystalline silicon oxide, known as quartz, predominates among the larger sand grains. Simple carbonates are among the few carbon compounds of soil that can be separated and identified. The great majority of the compounds of both groups that predominate in soil are very complex and in many cases not well understood. This is one reason why any simple discussion of soil chemistry is confronted with the necessity of important omissions of facts or with a compromise with accuracy of statement.

The older textbooks on agricultural chemistry list 10 elements as essential to plant growth. Of the group, carbon, hydrogen, and oxygen come from the air and water, while phosphorus, sulphur,

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nitrogen, potassium, calcium, iron, and magnesium are obtained by the plant from the soil. Modern science is recognizing others, including manganese, copper, zinc, and boron, as essential to balanced growth. Most of the various mineral elements occur in the rocks from which soils are formed. By natural processes, particularly by the action of water, and over long periods of time, the larger rock grains are reduced to a very fine state of subdivision and are then able to play a part in furnishing nutrients to plants.

Soil Colloids

The chemistry of the fine clay portion, or what is technically known as the colloid fraction of the soil, has in late years taken a prominent place in soil research. A few years ago the term "colloid" was essentially reserved for use in highly technical literature, but the significance of colloids in industry, medicine, and other subjects has led to more common usage of this term. It always refers to very small particles, usually too small to be seen with an ordinary microscope. Such materials often form a jelly when proper quantities of water are present. Inorganic soil colloids are the residues of rock particles that have been washed for ages by water and through this washing have lost much of their lime, potash, and other mineral constituents. The mineral matter retained by the soil colloid contains plant nutrients that slowly become available for the use of plants growing in the soil. It is the storehouse for the years, near at hand. Over a long period the larger rock grains are reduced to colloidal sizes and thus play a part in furnishing nutrients to plants.

The character of the colloidal material of a soil varies widely with general group classification of the soils. Finer distinctions between somewhat similar soil groups are often difficult to make. In general, it may be said that the ratio of the quantity of silica present to that of alumina and iron oxide is the most important chemical characteristic of the soil colloid upon which to base judgment of the fundamental character of a soil, since other important differences usually vary with this factor, the constituents of which involve 50 to 90 percent of the total mineral matter of most soil colloids. The fundamental soil character indicated by the chemical character of the colloids may frequently be used to identify the general locality in which a soil was developed. For instance, a few years ago, after severe nation-wide dust storms, scientists collected a small sample of dust from snow in Vermont. Chemical analysis showed that this material undoubtedly came from a region west of the ninety-seventh meridian, which passes through eastern Nebraska and Kansas. Broad differences of this kind can be determined by soil chemistry. Smaller differences necessitate less certain interpretations from chemical data.

Since plant nutrition and agricultural practice are largely determined by the character of the soil colloids, it follows that good tillage and fertilizer practices developed by farmers are based upon knowledge of colloid behavior, even though that knowledge may have been gained through experience only and in total ignorance of either the term "colloid" or of the existence of such material.

Soil colloids affect the properties of soils in so many fundamental ways that it is difficult to refer to any soil function not related in some

way to this important fraction of the soil material. In dry-land regions the mineral colloid fractions have undergone only moderate chemical change from the action of water. They retain a large part of their original bases, such as sodium, calcium, and potassium. Their silica content remains high. The typical colloidal properties are very pronounced; that is, the colloids swell when water is added and disperse when agitated with greater quantities of water. When they are dispersed and the water content is reduced, they form jelly masses which, when further dried, become almost impervious to water. This last property of colloids makes irrigation and drainage very difficult, if not impossible, in certain localities. It is sometimes necessary then to change the colloidal properties by some means before these operations can be successfully undertaken.

Under prairie agricultural conditions the soil colloids have been a little more weathered and the accumulation of much organic matter in the surface soil has enhanced their fertility. In the northern forested regions, active changes in the soil colloids are under way. Organic and mineral matter at the surface is dissolved, dispersed, and transported downward, where it is concentrated in a layer containing much iron and organic matter. Sometimes this material acts as a cementing agent, giving rise to a layer of hardpan. The chemical composition of the colloids of such soils, described elsewhere as Podzols, is markedly different from that of other soil groups. In the Red and Yellow, or lateritic, soils, the colloids have undergone still different changes. Weathering has proceeded to a marked degree, leaving an excess of iron oxide and alumina, with a greatly reduced silica content. These soils are usually acid and have lost through base exchange a very large part of their original base constituents.

Base Exchange

Base exchange is a property of soils that has very important practical applications. When a simple salt, such as the ordinary fertilizer constituent muriate of potash (potassium chloride), is added to a soil, it does much more than simply increase the concentration of potash in the soil solution. Instead, some potassium changes places in the colloidal particle with calcium, sodium, and other mineral base elements, and these in turn enter into the soil solution. The result is that only a part of the potassium which was added in solution remains water-soluble. The increased concentrations of other constituents set free may enrich the soil solution in other ways and make it better balanced for plant growth. This process, by which one base goes from solution into insoluble form and another comes out into the solution to take its place, is known as base exchange. It is a great soil-conserving factor, since it retards the excessive leaching out of such valuable constituents as potash and ammonia. By base exchange it is possible to improve soils whose physical condition has become bad from excess of sodium. Hydrogen or calcium may be substituted for a part of the sodium. Sometimes exchange is accomplished by the addition of sulphuric acid in small-scale operations, or sometimes by the addition of calcium salts, such as calcium chloride, in irrigation districts. Base exchange takes place slowly from the action of water on soil colloids under natural conditions. The traces of carbonic acid in the water

replace lime and other constituents to form a colloid of increasing hydrogen content; that is, to form a more acid soil. Thus, when soil leaching has been excessive over long periods, soil acidity becomes an agricultural problem, both from the standpoint of intensity of the acidity and also from the depletion of various soil bases that has taken place through the base-exchange process.

Soil Acidity

Soil acidity is described by various terms, such as hydrogen-ion concentration, reaction, pH values, or exchange acidity. Each of these terms refers to a measurement of acidity in some form. In regions of low rainfall where leaching has not been excessive, acid soils are infrequent. In such regions the opposite of this, alkaline condition, frequently develops. The so-called black alkali (alkaline carbonates) regions of the West result from the accumulation of bases in a soluble form. Throughout the regions of moderate rainfall some moderately acid soils are found, and others are neutral or alkaline, depending to a considerable extent on the character of the parent material. In regions of high rainfall soils are usually acid to varying degrees unless their parent material is highly calcareous, and even then strongly acid soils are frequently found with underlying calcareous material only 3 or 4 feet, or even only a few inches, from the surface. A nearly neutral or slightly alkaline soil is frequently considered the best for agricultural purposes; however, no broad statement of this kind is justified.

The degree of acidity (pH) controls in a very significant way the adaptation of various crops and native vegetation to soils. For instance, cranberries can be successfully grown only in soils moderately to strongly acid. Alfalfa and various other legumes are ordinarily successfully grown only in slightly alkaline or in not more than weakly acid soils. Some of the great agricultural crops of this country, such as corn, are apparently indifferent to soil-acidity conditions within a fairly broad range. The application of lime in some form, either limestone, dolomitic limestone, or burnt lime, constitutes the ordinary procedure for correcting soil acidity. In order to ascertain what the lime requirement of a soil is, many factors must be taken into consideration, particularly the kind of crop to be grown. When lime is added, a typical base-exchange reaction takes place; i. e., the hydrogen of the complex soil colloid is exchanged for the calcium of lime. Acid soils are found within a great many soil series but predominantly in regions of high rainfall.

Soil Solution

As previously mentioned, soil solutions arise primarily from the action of water upon the colloidal soil material. All of the minerals taken up from soil by plants probably enter the plants through the soil solution. The water around the grains of fertile soils never contains a large amount of mineral matter in solution at one time, but the character of the colloids determines whether or not mineral matter will continue to dissolve rapidly enough to support continued good growth of plants. Part of the soil solution is utilized by the plants, another part is usually drained away, while in certain cases still

another portion seeps down to lower levels and collects in depressions until the concentration of the soil solution increases. Under certain circumstances it becomes too high for plant growth. Such soils are said to contain alkali, though they are not always really alkaline in character. They are, however, salty and often contain considerable quantities of ordinary table salt, as well as other salts such as calcium chloride and sodium sulphate.

Nature has provided that most plants may thrive in a fairly wide range of concentration of soil solution. Water extracts of some soils that produce good crops contain no large quantity of dissolved material, perhaps 15 to 100 parts per million. On the other hand, these same crops have been grown experimentally in the so-called tank agriculture, with many times this concentration of salts in solution.

Soil Organic Matter

The chemical nature of soil organic matter is so complex that only very general statements regarding it can be made here. Soil organic matter contains many compounds of varying properties. Some of it is intimately associated with the silicate minerals as a part of the soil colloids. It acts as a weak acid and is capable of holding large quantities of bases as a part of its composition. It also has basic properties, which enable it to combine with acid material such as phosphoric acid. Most of the compounds contain nitrogen and serve as food for the growth of bacteria, fungi, and various other forms of life. The processes of life, death, and decay leave byproducts that aid plant growth. The maintenance of an adequate supply of active organic matter is one of the important problems of permanent agriculture.

Soil Chemistry Research

The problems that soil chemists are called upon to solve are many and varied. Frequently they are concerned with only one phase of a broader agricultural problem where such sciences as physics, botany, and other branches of biology have a part.

There is space for only one example of a problem solved by soil chemistry. A few years ago it appeared that the repeated heavy applications of calcium arsenate used for control of the boll weevil of cotton had a detrimental effect on cotton yields in certain areas. It was evident also that the detrimental effects were much more pronounced on some soils than on others. Chemical investigations showed that this variation in toxicity of added arsenic was related to the free iron oxide content of the soils. Arsenic in the condition of that added forms a very insoluble compound with the iron oxide. Thus the red soils with relatively high iron contents showed but little detrimental effect, but caution was needed in applying arsenic to those of light colors.

Numerous problems are concerned with the causes of infertility of various soils, either in local spots or in large areas. Such problems are attacked in different ways depending upon the symptoms. In one area abnormal quantities of nickel and chromium were found, which probably were the detrimental constituents. In many areas the chemical information gained from acidity tests forms a basis for improved farm practice.

Much of the work of a soil chemist has no popular appeal. It involves the accumulation of chemical data related to soil classification and to other broad lines of soil work. Such data, which add to our knowledge of soils, aid in a more ready solution of practical problems as they arise.

MORE TECHNICAL SOIL CHEMISTRY

Soil consists of the decayed residues of minerals and of organisms that have existed upon it or in it. The organic remains are derived from the decay of both plants and animals and of animal excreta. As a rule the decayed products are mixed with fragments of the parent materials, which are still subject to further change by physical and chemical weathering, i. e., to further decay. As a rule, also, the soil contains living organisms such as plant roots, bacteria, insects, and large animal organisms; but these, however important they may be to the behavior of plant growth in the soil, are not usually considered as an essential portion of the soil itself.

The substances composing the soil exist for the most part in incomplete equilibrium with the environmental conditions and with each other. That is to say, the materials of the soil, while subject to change, actually change slowly in short intervals of time; or if they change rapidly, replacement of the changed material is likely to occur. In illustration of this, attention may be called to the very slow change of mineral fragments to fine soil material (clay) and to the rapid seasonal decay of vegetation and its frequent replacement. In general, the soil of a given area is likely to remain of essentially constant character from year to year unless subjected to artificial alteration at the hands of man or to some violent change as a result of disturbances of nature, such as storms.

The soil materials present in a given soil, so far as their chemical composition is concerned, depend in part upon the rocks from which they were produced, in part upon the climate (temperature and rainfall conditions), and in part upon the kinds of vegetation developed upon them.

This article is concerned with the character of the inorganic (mineral) components of the soil and its bearing upon certain aspects of soil behavior and use.

Mineral Composition of the Soil

Almost any of the entire list of chemical elements may be expected to exist in the soil. Indeed, a very large number of them have been shown to be present in many soils.²

However, the greater part of the inorganic portion of the soil consists of a relatively small number of elements. That this should be true is evident from consideration of the composition of the earth's crust from which they are derived. The sources of the soil are usually igneous rock, shales, or sandstones (including residues from carbonates). The approximate relative quantities of the mineral components of these sources, as given by Clarke (65) ³ are shown in table 1.

Of the minerals listed in table 1, quartz is essentially silica (SiO_2), an oxide of the element silicon (Si), of which sand is the form most commonly known. The feldspars, clay, hornblende, pyroxene, and mica are minerals called silicates which consist chiefly of the elements silicon (Si), aluminum (Al), and oxygen (O), in combination with each other along with considerable quantities of the elements iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), and usually with traces of other elements. It must be clearly understood that none of these elements exists as such in the minerals; they are always in chemical compounds. Limonite is one of the hydroxides of iron ($\text{Fe}(\text{OH})_3$). The carbonates are chiefly salts of calcium and magnesium, e. g., limestone (CaCO_3). Of the minerals listed as "Other minerals" the greater part also consists of compounds of silicon, aluminum, and iron.

It is not surprising, therefore, that soils, as decay products of these minerals, consist largely of the elements named above and that the most abundant of these are oxygen, silicon, aluminum, and iron.

²The significance of minor elements is treated elsewhere in this Yearbook, as are also various other topics with which soil chemistry is intimately related. Without further citation the reader is referred to other articles when additional details or meanings of terms are desired. Some of them are Water Relations of Soils, Soil Organic Matter and Soil Humus, The Physical Nature of Soil, Formation of Soil, and Soil Classification.

³Italic numbers in parentheses refer to Literature Cited, p. 1181.

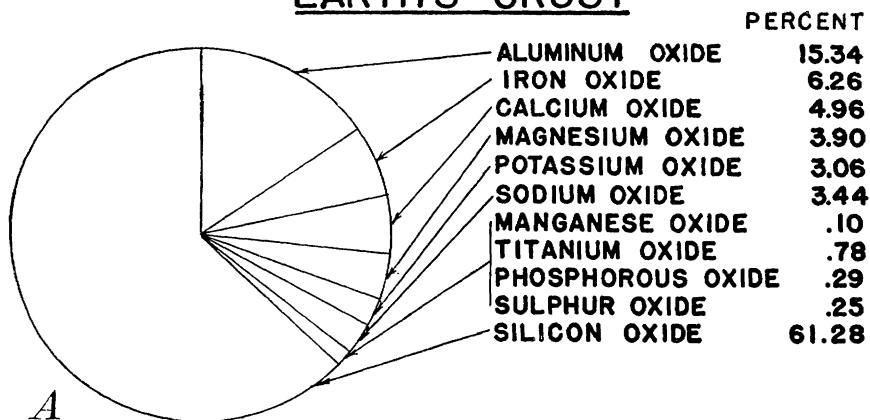
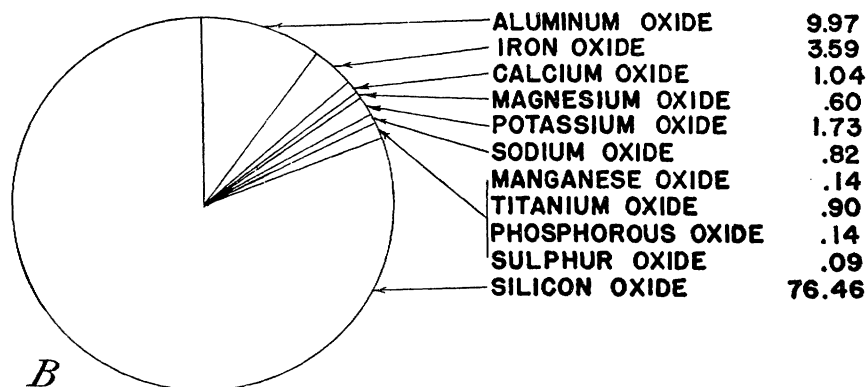
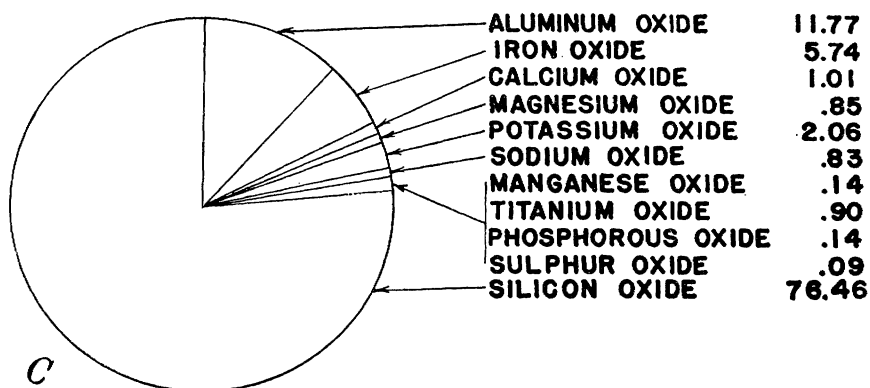
EARTH'S CRUST**A HORIZON****B HORIZON**

FIGURE 1.—The approximate composition of the earth's crust (*A*), and *B* and *C*, mean composition of the A and B horizons, respectively, of 18 representative soils.

Table 1.—*Approximate mean mineral composition of igneous rocks, shales, and sandstones*

Mineral	Igneous rocks	Shales	Sandstones	Mineral	Igneous rocks	Shales	Sandstones
	Percent	Percent	Percent		Percent	Percent	Percent
Quartz.....	12.0	22.3	66.8	Mica.....	3.8		
Feldspars.....	59.5	30.0	11.5	Limoneite.....		5.6	1.8
Clay.....		25.0	6.6	Carbonates.....		5.7	11.1
Hornblende and pyroxene.....	16.8			Other minerals.....	7.9	11.4	2.2

In the chemical analyses of both minerals and of soils it is usual to express the results obtained as the percentage quantities of the oxides of the elements determined. When the sample has been freed of organic matter and water, the sum of these percentages approximates 100 very closely. It must not be supposed, however, that the minerals or soils contain the free oxides of the elements except in certain instances. This method of stating the composition permits a mode of expression of the relation between soils and their parent minerals shown in figure 1.

Figure 1, *A* expresses the approximate mean composition of the earth's crust, as estimated by Clarke (65). Figure 1, *B* and *C*, expresses in corresponding terms the mean composition of 18 ignited soils. The soils are all agriculturally important ones. Figure 1, *B* shows the mean composition of the A horizon (surface soil) and *C* the mean composition of the B horizon (see *The Physical Nature of Soil*, p. 889). Were the mean analytical values of all soils obtained the result would probably not differ widely from the figures given. From these figures it may be seen that both soils and minerals have the same general composition, when expressed as oxides. The transformation from minerals to soils is accompanied by a marked decrease in the percentages of calcium, magnesium, potassium, and sodium oxides, ordinarily termed the bases, and relatively smaller losses of aluminum and iron oxides, while the average silica content is relatively higher. It may be particularly mentioned that while all soils contain small quantities of numerous other elements, including titanium, phosphorus, sulphur, and many others, the distribution of these elements in the minerals is not so general.

The process of transformation of parent minerals into soil is called weathering and involves the breaking down of the minerals and rocks into smaller fragments, their segregation in various ways (physical weathering), and also chemical changes which produce different substances (chemical weathering). Through these processes the soil becomes a complex mixture of particles of various sizes. The distribution of particles of different sizes varies widely in different soils, and the relation is determined by mechanical analysis. The relative quantities of the particles determine what is known as soil texture.

The chemical composition of the particles of various sizes is also very different in different soils and even in any given soil. In general the larger particles are similar to, or identical with, the minerals from which the soil is derived, since for the most part they are mineral fragments. On the other hand, the very small particles are likely to be very different in chemical composition and chemical behavior from the parent minerals. This statement applies chiefly to particles which when suspended in water are of a maximum diameter of 0.002 mm (0.00008 inch). (To avoid the use of such small decimal values, 0.001 mm is called 1 micron.)

For the most part the very fine particles exist in the soil as complex compounds called aluminosilicates, which are capable of holding in chemical combination certain basic and acidic radicals (to be discussed later) and water. The chemical changes from rocks and minerals to clay are very involved and cannot be given in detail; in fact, the steps are not fully known. An example of the kinds of changes believed to take place follows.

The clay of most soils is derived chiefly from feldspars, a frequently occurring kind of which is orthoclase. It has the chemical composition represented by the formula KAlSi_3O_8 . This mineral slowly reacts with water and produces a series of compounds. They may be represented by the following equations, which present a sort of picture of what may occur as a result of mineral decay:

- (1) $\text{KAlSi}_3\text{O}_8 + \text{H}_2\text{O} \rightarrow \text{KOH} + \text{HAlSi}_3\text{O}_8$
- (2) $\text{HAlSi}_3\text{O}_8 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{AlSi}_3\text{O}_9$
- (3) $\text{H}_3\text{AlSi}_3\text{O}_9 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{AlSi}_2\text{O}_7 + \text{H}_2\text{SiO}_3$
- (4) $\text{H}_3\text{AlSi}_2\text{O}_7 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{AlSiO}_5 + \text{H}_2\text{SiO}_3$
- (5) $\text{H}_2\text{SiO}_3 \rightarrow \text{H}_2\text{O} + \text{SiO}_2$

Of the above compounds the potassium hydroxide (KOH) leaches out of the soil through drainage, as does also a part of the silicic acid (H_2SiO_3). A portion of the potassium hydroxide reacts with the finely divided aluminous silicates and a portion of the silicic acid loses water and forms secondary silica which remains in the soil. If the parent feldspar, or other mineral, contains iron (Fe) it may behave just as does aluminum and produce ferrosilicate. Often, however, especially when soils are developed in moist climates, the chemical changes of similar type go farther and leave the iron in the form of ferric hydroxide ($\text{Fe}(\text{OH})_3$) of ferric oxide (Fe_2O_3). Also to some extent the further chemical decay of the aluminous-silicates may leave in the soil some aluminum hydroxide ($\text{Al}(\text{OH})_3$) or alumina (Al_2O_3). In case the minerals contain other basic elements, such as calcium, magnesium, or sodium, their fate is similar to that of potassium. The portion of the bases dissolved in water is in part reabsorbed by the soils through which they pass, and as animal and plant remains decay in the soil their inorganic residues become part of the soil. Frequently their basic constituents become combined with the clay.

While the picture presented above is not sharply defined and the usual quantitative significance is not assigned to the equations, yet it is apparently true that changes of the type indicated actually do occur. The relative amounts of the compounds present in different soils vary widely, depending upon parent material, climate, age, and other conditions.

In addition to compounds of the kind mentioned above, the clay of a soil may contain a considerable number of other components varying in quantity and character. Among these the most abundant and the most widely distributed is the oxide of titanium (TiO_2), which ranges in quantity from a fraction of 1 percent to several percent. Essential components also are compounds of sulphur and nitrogen, which are for the most part, but not wholly, associated with the soil organic matter. Present also, as indicated in figure 1, are compounds of phosphorus.

Soil Colloids and Their Composition

The greater portion of the clay found in soils, as well as of the organic matter, can by suitable treatment be suspended in water and made to remain so suspended for considerable periods of time. This suspended material possesses many of the properties of glue, albumins (such as egg white), and other plastic materials, which are collectively known as colloids, from the Greek word *kolla*, glue. It is therefore known as soil colloid. By arbitrary definition the term is applied, at least in the Department of Agriculture, to that portion of the soil consisting of particles 1μ or smaller in diameter. However, it is probable that not all particles of these dimensions possess marked colloidal properties. It is rather difficult to comprehend quantities so small as are the colloidal particles of the soil. Recent work indicates that the average diameter of the soil colloid particles is about 0.05μ and that it would require 500,000 particles to make a continuous row 1 inch in length. The average specific gravity of these particles is 2.7; assuming for purposes of calculation⁴ that they are spherical, which they appear to be when suspended in water, a pound of them opened up and spread out as a flat surface would cover an area of approximately 5 acres. As compared with the colloids, the number and surface of the larger particles are negligible.

It has been clearly shown that the greater part of the important functions of the soil such as moisture relations, fertility, response to cultural treatment, etc., resides in the soil colloid and that the chemistry of the soil in its relation to plants

⁴ Certain observations indicate a possible spherical form for the colloidal soil particles when associated with much water, as is the case in a suspension. However, stronger evidence points to the preponderance of either plate or rod shapes. Some of the evidence is: (1) If dilute soil colloid suspensions are stirred or caused to rotate in a flask, definite streaming effects are observed; (2) there is a big difference in ultramicroscopic counts made in random motion compared to similar counts made in an electric or electromagnetic field; (3) scintillating effects are observed in the ultramicroscope; (4) results of X-ray analysis also point to a platy structure in some of the clay minerals.

is essentially the chemistry of the soil colloid. The enormous surface of the soil colloid only partly explains these facts. It is also evident that different soils have colloids of differing composition.

From extensive studies it seems clear that the aluminosilicic acids, and related compounds, which are assumed to exist in the soil colloid, belong to the type of compounds known as amphoteric. This means that they are capable of chemical reaction with bases such as the hydroxides or oxides of calcium, magnesium, potassium, and sodium to form salts somewhat less stable than the acids themselves. At the same time they are able to combine with acidic constituents such as the acid radicals of phosphoric acid, arsenic acid, sulphuric acid, etc. These radicals, like the basic elements, are not firmly held in the presence of water and tend to split off as soluble components of the soil solution.

The soil colloid may, then, when dispersed in water, be regarded without serious error as consisting of minute particles made up of one or more, usually several, of the acids mentioned (p. 919), in which a part of the hydrogen of the acids is replaced by bases and part by acid radicals. Usually the acids and bases present do not completely saturate the colloids. When the colloids are separated from the water by filtration and allowed to become apparently dry at moderate temperatures, they still contain water, which is given off by decomposition when they are heated to dull redness. This is the combined water of the colloids. In addition to the combined water, bases, acid radicals, and colloidal acids, soil colloids always contain organic matter in varying quantities, some of which is presumably chemically combined with the inorganic matter and some presumably only intimately mixed with it. The whole of this material is sometimes called the colloid complex of the soil. It is unfortunate that because of the character of this complex it has as yet been found impossible to separate it into its individual components. For the most part these components are not soluble as a whole in any solvent, and none is volatile without decomposition at any temperature. The fundamental methods of purification by fractional crystallization and distillation therefore cannot be applied to them. The individual components can be arrived at only by inference from the behavior of the complex. In dry soils the clay and colloid may exist either as films on the larger mineral particles, as aggregates of the complex itself, or as more or less hard concretions. They serve as the binding material of soils.

The Soil Solution

The foregoing paragraphs have indicated that the soil is a very complex mixture of substances which in general persists from year to year without essential change except under special conditions. The components of this mixture must therefore, in general, be very insoluble in water. While this is true, at least some of the substances must be soluble to a limited extent if the soil is to serve as a means of transferring plant food to growing vegetation instead of serving only as a sort of framework for plant support. As a matter of fact, all the substances in soil are soluble to a limited extent in the soil moisture, which ordinarily surrounds the soil particles in humid regions, and indeed at intervals in any soil capable of supporting plant growth. The quantity of such dissolved material is always small at any one time even in the most fertile soils, and the concentration of the solution varies greatly with the quantity of water present. The materials present in the soil solution, as well as their quantity, vary also with the character of the soil.

If the soil solution is withdrawn from the soil by drainage and replaced by pure water or if the soluble materials are removed by plant growth, the supply of plant nutrients is continually renewed by the dissolving of more material from the soil. This renewal of plant nutrients in the soil solution is perhaps the most important function of the soil colloid. The best agricultural soils hold a sufficient quantity of the necessary plant nutrients to supply the requirements of the plants growing upon them unless the depletion is excessive by reason of crop removal, leaching, or erosive activities. The decay of vegetation assists in maintaining an adequate soil solution, since the mineral residues of plant decay return the plant nutrients to the soil in chemical forms particularly suited to the purpose. In cases of overcropping or other means of excessive depletion of available plant nutrients from the soil, restoration must be brought about by manures or artificial fertilizers.

Many soils used for agriculture contain insufficient quantities of clay and colloid; or the colloid is of such character that soil solutions adequate for plant growth are not produced. In such soils suitable nutrients must be added, if satisfactory plant yields are to be obtained. In such cases it is usually necessary

also to add the nutrients at frequent intervals. It is possible, however, to build up many depleted soils by means of fertilizers so that longer periods between fertilizer additions are practicable.

There are several methods of extracting soil solution from the soil, none of which is wholly satisfactory. When such soil extracts are obtained, it is generally found that the concentration of the soluble salts in the solution is less than is required in artificial nutrient solutions to produce corresponding results. It is also found that the soil solutions have a higher concentration of dissolved solids when the quantity of water present is small than when it is increased. Neither of these things should be true were the solutions made from pure salts in adequate quantity. It seems that in part at least these relations are to be ascribed to the presence of the colloids in the soils. In general, the concentration of any solution is usually greatest in the film adjacent to any solid surface, and none of the extraction methods satisfactorily remove all the soil solution adhering as a moisture film on the enormous surface areas presented by soil colloids. It is probable, however, that most of the effects of soil colloids upon solution are due to the behavior discussed later under the heading Base and Acid Exchange.

That the soil solution as such plays the dominant role in transferring soil material to plants is evident from the long-known fact that nutrient solutions can be prepared that will nourish plants and apparently furnish every essential except physical support and aeration. Recent large-scale experiments along this line have been extensively publicized, but yet it has not been fully demonstrated that such efforts promise economically practical results, at least when conducted out of doors.

Base and Acid Exchange

The soil colloids contain varying quantities of elements or groups of elements that by suitable treatment may be removed wholly or in part without destruction of the colloid complex. A part of these elements or radicals is believed to exist in the presence of water as ions, that is, as electrically charged particles similar to those of ordinary salt solutions, but with the difference that the free movement of the ions associated with the soil colloid is impeded by the presence of the insoluble colloid complex. The extent to which this separation of the soil colloid into ions takes place is chiefly dependent upon the colloid composition and the quantity of water present. If the ions present at any one time are removed, the colloid continues to ionize until for a given colloid no more ions can be produced.

One method that may be used to determine the quantity of material that may readily be separated from a soil colloid (the exchangeable bases and anions) is known as electro dialysis. To carry out this process the soil or colloid is placed in a suitably designed three-compartment vessel so that when a direct current of electricity is passed through the suspension of the colloid in water the positively charged ions are carried into one portion of the cell and there, through discharge of electricity and reaction with water, are converted into hydroxides of the metals. In this portion of the cell (the cathode compartment) are found the hydroxides of calcium, magnesium, potassium, and sodium and smaller quantities of other bases. The positively charged hydrogen ions of the colloids are released as gaseous hydrogen.⁵ In another portion of the cell (the anode compartment) are collected the negative ions such as hydroxyl (OH^-) and the negatively charged radicals of acids such as the phosphate radical (PO_4^{--}), the sulphate radical (SO_4^{--}), together with a little of the silicate radical (SiO_3^{--}), which is able to pass through a membrane. Along with these are smaller quantities of such other negative ions as may exist in the colloid. These always include small quantities of the radicals of hydrochloric acid (Cl^-) and of nitric acid (NO_3^-). When these ions are discharged at the anode the hydroxyl ions form water and oxygen gas and the others the corresponding acids. When soil colloids are first subjected to this electrolytic process they are fairly good conductors of the current, and rapid removal of the ions occurs. As the process continues the removal slows down and eventually becomes very slow, with a corresponding decrease in current flow. In carrying out this process usually the greater part of the sodium and calcium of the colloid is removed at the cathode, and all the sulphate, chloride, and nitrate are removed at the anode.

⁵ It must not be inferred from this statement that a hydrogen-free colloid residue remains in the middle chamber of the apparatus. As a matter of fact the residual colloid is of higher hydrogen content. This is because its reaction with water replaces the hydrogen ions and furnishes nearly all the hydroxyl ions for anodic current flow.

Only a small part of the magnesium and potassium is removed at the cathode and part of the phosphate at the anode.

This very brief and incomplete outline of electrodialysis is given here because it furnishes a background for the picture of the soil clay or colloid in water as made up of minute particles of insoluble material electrically charged and surrounded by various electrically charged particles consisting of the elements and radicals which when discharged and brought into solution give to the solution the plant nutrients that are not present as such. It also gives a picture of the renewal of this solution by continued ionization and discharge. If now the available plant nutrients in a soil are regarded as only those portions that may be brought into solution, it will be observed from the above discussion that by no means all the plant nutrients in a soil are immediately available for plant growth. This is particularly true of potassium and phosphoric acid.

A more commonly used means of estimating the available plant nutrients in the soil or its clay fraction, as well as of studying the chemical relationships of soils, is the determination of the exchangeable bases by means of extraction with salt solutions. It has long been known that if a soil or its clay is treated with a strong solution of a neutral salt such as sodium chloride (NaCl), barium chloride (BaCl_2), or ammonium acetate ($\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$), and the suspension filtered, the filtrate will contain the chlorides or acetates of calcium, magnesium, and potassium, as well as of other like elements present in the soil. The elements so removed are collectively known as the exchangeable bases. Their kind and quantity are determined by the character of the soil and its previous treatment, and they are therefore a valuable indication of soil character and soil needs. Their removal from the soil by salt solutions is dependent upon the type of chemical reaction known as exchange and in soils may be indicated by the following schematic equation: $(\text{H}, \text{Ca}, \text{Mg}, \text{K}, \text{Na})_x \text{ clay} + 3 \text{ NH}_4\text{Ac} \rightarrow 3 [\text{HAc}, \text{CaAc}_2, \text{MgAc}_2, \text{KAc}, \text{NaAc}] + (\text{NH}_4)_x \text{ clay}$.

The materials indicated within the parentheses on the right-hand side of the above equation are in solution in water, and their quantities may be accurately determined. The sum of the hydrogen, calcium, magnesium, potassium, sodium, and other similar elements is chemically equivalent to the ammonium (NH_4) remaining with the colloid complex. These quantities are usually expressed as milliequivalents per 100 g of dry soil or colloid.

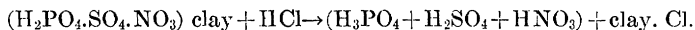
The quantity of ammonium remaining in the soil after the above-described treatment and adequate washing may be accurately determined and also expressed in milliequivalents of dry soil or colloid. (If other salts than ammonium acetate are used the same relations are found though the quantities are not always exactly the same.) This quantity, however determined, is known as the base-exchange capacity of a soil or colloid. The ratio between the exchangeable bases (exclusive of acid hydrogen) and the base-exchange capacity of a soil is known as the degree of base saturation of a soil or colloid. It is usually expressed in percentage. Thus if a soil has a base-exchange capacity of 30 milliequivalents per 100 g and the sum of its exchangeable bases is 10 milliequivalents, its degree of saturation is one-third, or 33½ percent. Very great differences are found in soils both with respect to their base exchange capacities and degree of saturation.

The normal soils of the humid areas in general have a low degree of saturation, which means that they do not have as much of the basic elements as they could retain were the leaching less by reason of lower rainfall. If, however, they have a high base-holding capacity and moderate leaching, they may have quite adequate storage of plant nutrients for maintaining plant growth under proper conditions of use. In the semiarid and arid areas the base-exchange capacity and degree of base saturation are both likely to be high, and no fertilizers are necessary except in the case of some particular soil deficiency due to local conditions. In such soils water supply is usually the limiting factor. Occasionally such soils may not only be saturated with bases, but an excess of water-soluble salts may be present to a degree that limits satisfactory use.

The soils and their colloids when in contact with water also have a part of their acidic content in the form of negative ions. Some of these are so readily liberated from the soil by moderate leaching that they are not found except in minute quantities in humid soils. In subhumid or arid soils they are likely to be found in larger quantities but by reason of almost complete removal by moderate leaching are not ordinarily considered as a part of the colloid of the soil. Examples are the negative ions of hydrochloric acid (Cl), nitric acid (NO_3), and others. In humid areas also the sulphate ion is retained to some degree by the soils of

low base-holding capacity and is normally present in the soils of both the humid and arid areas. In the latter case the presence of moderately soluble sulphates, such as calcium sulphate, leaves open the question of the degree to which the sulphate is a part of the colloid complex. In all fertile soils phosphates are present, and phosphate ions are produced by contact with water.

The behavior of the acid ions when the soils or their colloids are electro-dialyzed or treated with very dilute acid is similar in type to the behavior of the bases and may be schematically represented by the following equation:



It must be recalled, however, that since the colloid complex is amphoteric the treatment with hydrochloric acid also removes exchangeable bases through replacement by hydrogen. Here as with the base exchange the materials shown within parentheses on the right-hand side of the equation, however gained, are soluble in water, and the chloride-clay is not soluble in the presence of the hydrochloric acid. The mixture may be filtered and the acids present in solution determined quantitatively, although with continued washing chlorine is largely replaced by hydroxyl (OH).

For historical reasons not pertinent here, the quantities of acids found by electro-dialysis or anionic exchange are often expressed not as acids or acid radicals but as oxides. For example, SO_3 instead of H_2SO_4 is used, P_2O_5 instead of H_3PO_4 , etc. This is, of course, not true of such acids as hydrochloric acid or hydroiodic acid, in which the quantities of the elements are reported.

By no means so much is known of the acid-exchange relations of soils as of their base-exchange relations. This is probably because less decisive data have been obtained on acid exchange in relatively fewer investigations rather than because the subject is less important. The concentration of negative ions in soil suspensions is usually very low in humid soils. In relation to plant growth it appears that the most important of the anions is that of phosphoric acid, and it has been shown that soils hold phosphates in unavailable form when the soil colloids are high in content of iron oxide. It seems probable that this is because of the extreme insolubility of the phosphate of iron. Probably no portion of the field of soil research offers richer rewards than does that of the anionic relations of soils.

Hydrogen-Ion Concentration of Soils

When a soil or its extracted colloid is mixed with water, the mixture becomes a conductor of an electric current, and it is therefore believed that ionization of the colloid complex occurs. Since, for the most part, the colloid is insoluble in water the colloid particles may be imagined as surrounded by a sheath of ions something after the order of the highly imaginative diagram shown in figure 2 (312). The dissolved ions are not wholly free, but part of them are held more or less closely in the neighborhood of the insoluble nucleus.

In all normal soils the predominating ions throughout the soil solution are those positively charged (cations). These include various metallic ions such as calcium and potassium as well as hydrogen ions, which are characteristic of acids. The electrical charges of these positive ions (cations) are for the most part balanced by corresponding negative charges on the immobile anions, which are the colloidal particles. It is probable that only a few of the exchangeable cations are actually dissociated at one time.

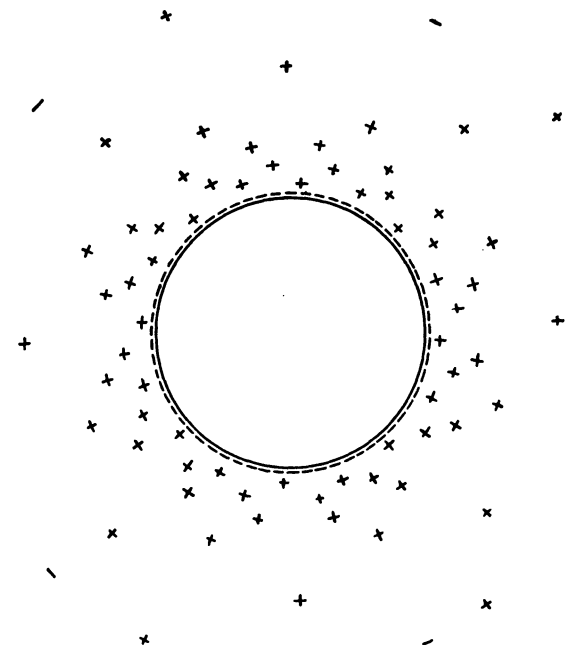
The relative quantities of the various ions as well as the total ion concentration in a soil suspension are largely determined by the character of the colloid and particularly by the kind of basic elements in the colloid. In soils of the semiarid and arid areas hydroxyl ions usually predominate over the hydrogen ions, owing to the quantities of bases present. Also other negative ions such as sulphate and chloride ionized from soluble salts are frequently present in these soils. As rainfall and attendant leaching are increased, hydrogen ions progressively replace such metallic ions as calcium and sodium, until in Podzol soils the influence of the presence of hydrogen ions is pronounced. But in the other soils such as Chernozem or Prairie, the plants return bases to the soil and prevent the development of a strongly acid condition.

In any case soil suspensions range from weakly acid to weakly basic, depending upon the character of the colloid. The degree of acidity, sometimes called the

soil reaction, is most simply indicated by the effect of the suspensions upon indicators such as litmus or similar more sensitive dyes that change color when made

acid or alkaline. In the case of litmus, alkalinity of the soil is indicated by a blue color and acidity by a pink color when a paper stained with the dye is dipped into the soil suspension. The litmus indicator, once used extensively for determination of the degree of acidity (or alkalinity) has more recently been largely replaced by many other dyes. The acidity of the soil and the condition of the soil, particularly with respect to bases, which acidity connotes, are important factors in its adaptability to particular uses and in determining the necessary treatment. Acidity in its broader sense has been carefully studied, and a method of expressing it in simple terms has been developed that, while extremely technical, is now very frequently used in even the most elementary soil discussions.

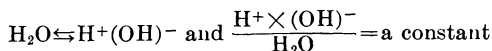
In the simplest terms, whether a soil is acid or alkaline depends upon the presence in the soil suspension (therefore in moist soils) of an excess of hydro-



+ CATIONS, INCLUDING HYDROGEN IONS
- ANIONS, INCLUDING HYDROXYL IONS

FIGURE 2.—Diagram of an imaginary colloid particles suspended in water.

gen or of hydroxyl ions. These ions are both present in pure water in exactly equal though very minute concentrations. Expressed graphically, the relations are:



where the quantities are 1 g of hydrogen ions and 17 g of hydroxyl ions in 10,000,000 liters of water. Ordinarily such concentrations are expressed in terms of the concentration of hydrogen ions, or their chemical equivalent, per liter where the unit is 1 g of hydrogen ions per liter. Therefore the concentration of

hydrogen ions in pure water is $\frac{1}{10,000,000}$ or 0.0000001 of a unit concentration.

To express exactly the concentration of such acids or bases as exist in soils and other substances of a like order of acidity would involve the use of awkward decimals or fractions. Consequently a system has been evolved for the more convenient expression of such small concentrations.

The concentration of hydrogen ions in pure water, as stated, is $\frac{1}{10,000,000}$.

The logarithm of this number is -7 , and any acid or base concentration may be compared in terms of this logarithm. The various values are called pH values, a term adopted without explanation of its derivation by a Danish scientist, S. P. L. Sorensen, and now in common use. Expressed in a slightly different way, the pH values of weak acids or bases are the logarithms of the reciprocal of the hydrogen-ion concentration. The hydrogen-ion concentration of water in terms

of pH is therefore 7; any aqueous solution more acid than water has a lower numerical value than 7; and any solution less acid than water will have a pH value greater than 7.

The numerical expressions developed are as follows: A soil having a pH value of 6 is a very weak acid but has 10 times the concentration of hydrogen ions present in pure water. Soils having a pH value of 5, 4, 3, and 2, respectively, are 100, 1,000, 10,000, 100,000 times as acid as water. No soils of lower pH values are known, but if one were found of a pH value of 1 or 0 the relative acid strength would be 1,000,000 and 10,000,000 times that of water. Since as hydrogen ions decrease in water the hydroxyl ions must increase correspondingly, it follows that a soil suspension having a pH value of 8 is 10 times more concentrated than pure water in respect to hydroxyl ions and this rate increases with increase of pH values until at a pH value of 14 the soil suspension would have 10,000,000 times the concentration of hydroxyl ions present in pure water. No normal soil approaching this pH value is known. Indeed the range of pH values of arable soils is normally between the limits of 4 and 9. This form of expression of soil acidity or alkalinity is used merely for the convenient expression of soil reaction in whole numbers. When acid or alkaline concentrations beyond the range of the pH scale are encountered (they never are in soils), the more ordinary modes of expression of concentration used in science are employed.

It is beyond the scope of the present discussion to enter into detail concerning the methods used in technical laboratories for the exact determination of the pH values shown by soils. A number of different schemes are employed for preparing a suitable device for making these measurements. Details are given in a circular published by this Department (371).

One method for determination of the approximate pH values of soils has extensive application. It is the use of a series of soluble dyes each of which changes color within a narrow range of pH values. There is a sufficient number of these to cover normal soils. These sets of dyes and corresponding color charts are marketed by various firms either alone or with other devices for making approximate estimation of fertilizer needs (16).

While agricultural soils may have pH values between the limits 4.0 and 9.0, the great majority of surface soils under cultivation actually have values between 5.0 and 7.5.

The chemical factors underlying the relation of soil pH value to plant growth are complex. Some plants appear to be affected directly by the intensity of acidity. In other cases, a more important factor is the lime content or the calcium-ion concentration, with which pH value is usually correlated to some degree. As bases, particularly calcium, are leached out or taken up by plants, hydrogen ions take their place in the soil colloid. Sometimes, however, the simpler calcium compounds such as calcium sulphate may provide an adequate concentration of calcium ions for various plants in a somewhat acid soil. Furthermore, an increase in the hydrogen-ion concentration (lower pH) tends to increase the solubility of aluminum. This is frequently a detrimental factor. The presence of free calcium carbonate, ordinarily desirable, which normally accompanies a soil of pH 7 or greater, is ruinous to certain plants, presumably in part at least because it prevents an adequate quantity of iron or other essential ions from dissolving in the soil solution. Soil acidity may vary to a detectable degree in a particular soil in different seasons of the year; it may be altered by growing plants and by the decomposition of organic matter. The continued use of certain fertilizer constituents may have a marked influence upon soil pH value. Such changes are sometimes beneficial and sometimes detrimental, depending upon the character of the soil and the crops to be grown.

It is in general true that a soil of low pH value is deficient in bases or other plant nutrients. It should be mentioned also that the normal pH value of a soil is dependent upon the character of the soil colloid as well as upon the degree of base saturation of the colloid. For example, a completely debased colloid of a lateritic soil may have a pH value much higher than a completely debased colloid of such soils as the Chernozem or Gray-Brown Podzolic group. pH values taken alone are therefore not indicative of comparative impoverishment of soils except within narrow limits of soil types.

Excessively high pH values of soils are also indicative of unfavorable soil conditions, particularly as regards the difficulty of percolating water through them. Frequently, the high pH value of a soil is due to the presence of soluble salts, a

condition that can sometimes be remedied by leaching. Sometimes it is due to the presence of base-saturated clays, especially sodium clay, in which case remedial leaching can be hastened by adding calcium salts to the water used.

It should also be mentioned that the pH values shown by soils bear no direct relation to the total acidity of the soil. This latter quantity is measured by the difference between the total base-exchange capacity and the quantity of bases liberated by electro dialysis or some other exchangeable-base method of measurement. It is for this reason that pH determinations alone do not furnish sufficient information for determining the lime requirement or other remedial measure for securing a desired pH value. From the chemical standpoint, lime requirement means the quantity of lime necessary to bring a soil to a definite arbitrary pH, such as pH 7. However, since the lime requirement of plants differs widely, this term has a varying agricultural significance.

Classification of Colloids

There is as yet no general agreement concerning the composition of the individual components present in any given colloid. Different views exist because of the present inability to isolate these components. There is no dispute, however, concerning the differences in composition of colloids as shown by analyses.

If the relative quantities of silica and of iron oxide and alumina are expressed in chemical equivalent quantities, it appears at once that markedly different quantities of the constituents characterize the colloids of the different soils. This ratio, the silica-sesquioxide ratio, is obtained by dividing the percentage amounts of the constituents by their formula weights of the constituents and then comparing the resulting quotients by dividing the equivalent of the silica by the sum of the equivalents of the alumina and iron oxide.⁶ The colloids of the various soil groups have widely varying relative quantities of these components. In a similar manner the relative quantities of silica and alumina and of silica and total bases are shown to vary between wide limits.

It will be observed that the colloids of the Chernozem soils have essentially the same colloid composition throughout the profile, or at least to the depths examined. The same is also true of the soils belonging to the lateritic group. There is, however, a wide difference between the composition of the colloids of the two groups, as indicated by the silica-sesquioxide, silica-alumina, and silica-total base ratios and the combined water.

From the analyses and derived data of the Podzol colloids it has been found that there are wide differences of composition in the various horizons. The A horizons have relatively high silica ratios and the B horizon low ratios. The combined water is low in the A horizons (when the organic matter is low) and high in the B horizon. In studying these relations it may be observed that in the Prairie soils are found values intermediate between the Chernozems and the lateritic soils. In the Gray-Brown Podzolic group the ratios in general lie between those of the Podzols and the lateritic group. In the case of the Laterites, of which examples are found only outside the continental limits of the United States, the characteristics of the lateritic soils are accentuated.

The primary purpose in presenting the points just made is to draw two inferences: (1) The relationship shown between composition of the colloids and the field classification of soils emphasizes the dependence of the essential soil characteristics upon the character of the colloid; (2) from the wide variation in colloid composition it can be concluded that no blanket specifications for agricultural practices can be justified. It is especially to be noted that the quantity of colloid found in soils bears no direct relation to its composition. In each of the great soil groups wide textural variations are found. In general, however, the surface soils have less colloid than the B horizon of the same soil.

⁶ In any elementary chemistry textbook can be found the atomic weights, from which the various formula weights involved here are readily obtainable. Let us assume that a colloid contains 45 percent of silica (SiO_2), 25 percent of alumina (Al_2O_3), and 10 percent of iron oxide (Fe_2O_3). The respective formula weights are 60.1 for SiO_2 , 101.9 for Al_2O_3 , and 159.7 for Fe_2O_3 . The quotients from division of percentage by formula

weight are then $\frac{45}{60.1}$ or 0.748 for SiO_2 ; $\frac{25}{101.9}$ or 0.254 for Al_2O_3 ; and $\frac{10}{159.7}$ or 0.062 for Fe_2O_3 . The silica-sesqui-

oxide ratio would then be $\frac{0.748}{0.254 + 0.062} = 2.37$.

Other Soil Properties Determined by Colloids

Many, though not all, of the important agronomic characteristics of soils depend upon the quantity and kind of colloid present and upon the state of aggregation of the colloid. It will be possible here to point out only a few of these relations for the primary purpose of showing that intelligent soil use must be based upon knowledge of colloid behavior. It is not essential that this knowledge be gained from books. Experience is an excellent school even though expensive. Proper treatment of soil, so far as it is followed, has been learned for the most part through age-long experience with soils.

The swelling of soils when moistened is caused almost wholly by the absorption of water by the colloid, and its extent with any given soil type is roughly dependent upon the quantity of colloid present. Colloids from widely different sources not only swell to different degrees, but the resulting wet masses of soil possess very different properties.

Of course the shrinkage of soils on drying is the result of the loss of the moisture absorbed in the swelling process, and there are many differences in the resulting dry masses that are dependent upon the quantity and kind of colloid. These differences show themselves most markedly through the behavior of the soils on being worked when considerable water is present in them. The Laterite soils can be plowed when wet and will be friable when they dry out. On the other hand, soils with colloids of high silica-sesquioxide ratio and a high colloid content, such as the Prairie soils and Chernozems, behave very differently. If worked when wet they become puddled very readily and dry out to form highly compacted clods. The soils with colloids of high silica-sesquioxide ratio, such as the Prairie, Chernozem, and semiarid soils, also behave very differently when they are saturated with different bases. If the dominant basic element present is calcium, they tend to dry to a friable mass when worked at moderate moisture content. Sodium-saturated clays dry to unworkable hard clods. Such soils are also difficult to irrigate because their high swelling coefficient quickly stops further ingress of water, that is, they "freeze" at the surface. There are also marked differences in the behavior of soils toward erosion that depend upon the character and quantity of colloids.

Perhaps the most important soil property that is dependent upon colloid composition is the base-holding capacity. In general it may be said that soils of high base-holding capacity are those in which the colloids have a high silica-sesquioxide ratio, and unless subject to excessive leaching with water, as in the case of the Podzol soils, they have also a high exchangeable base content. They therefore have soil solutions, with adequate moisture, that are favorable for plant growth so far as their base content is concerned. Such soils ordinarily need no artificial supply of plant food or stimulant to plant growth, except the addition of phosphate in certain areas. Since the soil solution at any one time holds in solution only a very small fraction of the available plant food, the supply is continually renewed by the action of water upon the colloid. Such soils are regarded as permanently fertile. Of course this is true only in a very limited sense. In the areas where rainfall is high or the soils are shallow or both, such colloids may have been impoverished in plant food, and natural or artificial fertilizers are essential for the practice of successful agriculture. This condition holds particularly in the areas of Podzol soils and to a lesser extent in the areas of Gray-Brown Podzolic soils. In the Gray-Brown Podzolic soils the depletion of plant food may be remedied to a large degree by manuring and the use of artificial fertilizers. To a considerable extent the effects of such treatment may be carried over from one year to successive years. Also to a considerable degree normal erosion contributes to the maintenance of fertility by removing thin films of leached material, thus exposing new soil parent material for incorporation with the soil.

Contrasting conditions are found in those soils in which the silica-sesquioxide or silica-alumina ratios are low (the Laterites and lateritic soils). In such soils the silica-total base ratio is very high, i. e., the plant food reserves of the soil are very limited, and the soils have low base-holding capacity and are low in exchangeable bases. They therefore furnish inadequate soil solutions over any extended period. Such soils may be in a state of high fertility in case the organic matter of the colloid is large, since in general organic colloids have high base-holding capacity. But under cropping conditions in such areas as produce soils of these types (hot, moist climates) the organic matter quickly decays and disappears. The plant-food needs of normal crops must therefore be supplied by frequent applica-

tion of fertilizers. It is impossible for Laterite soils to keep bases in reserve supply to be slowly doled out to the plants by way of the soil solution. Instead the greater portion of unused bases of fertilizers is likely to be carried away by the first heavy rain. The same conditions exist to a less marked degree in the lateritic soils. In such soils no rebuilding of the soil is possible, but fertilizer requirements must be met through a dole system of frequent applications. In the lateritic and Laterite soils an additional colloid relationship presents itself in the fact that certain acid radicals, and in particular the highly essential radical of phosphoric acid, form very insoluble salts with certain colloid components. It is possible, therefore, for phosphorus deficiency to exist even when phosphates are present in large amounts. It even happens that soils of lateritic types may have more phosphates than are quite adequate for soils of higher silica-sesquioxide ratios and yet require additions of phosphates. It is probable that the unavailable phosphates of soils exist for the most part as insoluble salts of iron and aluminum.

Limited space forbids the detailed discussion of many other relations between soil behavior and the colloid composition. It seems certain that all the elements existing in traces in the soil exist as part of the colloid complex and behave in general as do silica, iron, and aluminum on the one hand or the more basic and acidic elements or radicals on the other. It is believed that sufficient evidence is available to warrant the statement that the same general chemical relations apply to soils and their colloids as are to be expected of any mixture of relatively insoluble substances that are amphoteric, that is, that possess both acidic and basic character; and that the colloids are as a rule partially saturated salts of such compounds. It is also clear that these colloids are of almost infinite variety but that the variations are such that they may be classified in a systematic fashion.

It is essential then that the composition of a given soil and more particularly of its colloid be accurately known in order most effectively to adapt its treatment to its primary use, the production of crops. It should be apparent from what is known that no single system of agriculture is suited to all soils but that adaptation of practice must depend upon soil character. At the same time it is recognized that only a start has been made in the systematic study of soils and that there is need of intensive study of soil chemistry in order to make completely clear the underlying causes of the physical and chemical properties of the soil. The results of such research will provide a more fully coordinated body of knowledge that will permit better soil conservation and soil use.